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Research Article

Experimental Study on Springback Properties of 6061 Aluminum in V-Bending

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ABSTRACT

Sheet metal bending is one of the most commonly applied methods among sheet metal forming operations. In this study, the springback behavior of aluminum alloys of different thicknesses was examined by performing v-bending processes at different die angles and widths. The experiments were carried out on 1 and 1.5 mm thick plates at die angles of 140°, 150° and 160° and three different die widths: 10 mm, 16 mm and 20 mm. In this experimental study, it was observed that springback decreased as the die width increased. As the die angle increased, springback values also increased. It has been observed that sheet thickness has little effect on springback. As the sheet thickness increased, the amount of springback decreased. The lowest springback value of 0.1° was obtained in the 1.5 mm thick specimen with a die width of 10 mm and a die angle of 140°. The highest spring-go value of -2.7° was obtained in the 1 mm thick specimen with a die width of 20 mm and a die angle of 140°. As a result of the variance (ANOVA) analysis, it was seen that the die width had a more significant effect (78.42%) on springback than the die angle. The effect of die angle on springback is 10.73%. As a result of the experiments and statistical analysis, it was seen that the parameter that most affects springback is die width.

1. Introduction

Aluminum alloys are widely preferred due to their low density, high strength properties and good corrosion resistance. 6XXX alloy is used in various non-aerospace components such as buildings, rolling stock, boat hulls, ship superstructures, and, increasingly, automotive components. Al 6061-T6 aluminum alloy is strengthened by heat treatment and is widely used especially in the automotive and aircraft manufacturing industries [1, 2].

Bending is one of the commonly applied methods in shaping aluminum sheet metals. The usage areas of shaped sheet metal sheets are pretty high. Sheet metal forming applications are widely encountered at many different technological levels, from high-tech industries such as automotive, aircraft, and defense to the white goods industry. Bending forming is one of the most basic and widely used sheet metal forming methods [3-5]. Bending operations also vary depending on various variables such as the shape of the sheet metal part, material properties, and production quantity. Different methods shape the sheet metal into the desired final forms. These methods are basically based on shaping the sheet material with the help of more rigid objects with the desired form. The most used of these is shaping made by placing sheet metal between molds made of cast iron or steel materials, which complement each other and are generally called male and female, and applying force [6-8].

Springback is significantly influenced by many factors. Umur et al. investigated DP steels' spring back/spring forward behavior with the v-bending process. Effects of material thickness, die/punch radius, bending angle, and rolling direction were investigated systematically [9]. The sheet material undergoes plastic deformation above the

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elastic deformation limit with the force applied in these forming processes. Therefore, there is still some elastic deformation within the total deformation. Elastic deformation forming process parameters: It causes backward or forward springing behavior depending on the mold or forming geometry, part geometry, and material properties [9-11]. Since spring back or spring-go means deviation from the desired final shaping geometry, predictability and minimizing this variability before forming becomes essential in terms of time and cost savings.

The most fundamental problem in bending operations is springback. Springback behavior in sheet materials is a forming problem in which multiple interactions of many elements, such as mechanical and dimensional properties of the material and forming variables, are involved. The springback during the bending process cannot be eliminated entirely, but some predictable and compensatory work can be done. The phenomenon of the part returning its elastic deformation due to a shaping process is called spring-back. Springback is affected by many process variables [12-16].

Researchers examined these variables in two groups. The first is the material properties that affect the formability, and the second is the process parameters. Material properties are modulus of elasticity, yield, and tensile strength, elongation, strain hardening exponent, plastic anisotropy, and strain rate sensitivity exponent. Process parameters can be listed as deformation rate, temperature, friction and lubrication, sheet pressing force, tool geometry and size, and material thickness [17-21].

Wei-pink et al. investigated springback behavior of 6016 aluminum alloy in hot stamping under different conditions using V-shape dies. Researchers reported that springback decreased significantly when the initial blank temperature increased to 500 °C. As the die holding pressure increased, springback decreased. As the die corner radius decreased, the springback decreased [21]. Material properties have a great impact on springback. Guan et al. examined the effect of artificial aging time on the bending and springback behavior of 6061 aluminum through the bending process. They reported that springback and cross-sectional deformation increased as the artificial aging time increased [22].

Choi et al. studied the mechanical properties, springback, and formability of W-temper and peak aged 7075 aluminum alloy sheets. The formability and springback of the W-tempered sheet are analyzed by simulations.
The researchers revealed that the WT process could potentially be used to produce high-strength aluminum sheets at room temperature as an alternative to hot and hot forming processes [23].

In this study, the v-bending behavior of aluminum sheets was investigated experimentally. The aim of this study is to investigate the effects of parameters such as sheet metal thickness (t), die angle (DA), and die width (DW) on the v-bending process. The effect of process parameters from the experimental results will also be examined by variance and regression analyses. In addition, the results obtained are aimed to be a guide that can be used for studies in the industrial field.

2. Experimental Study

2.1. Material

In this study, Al 6061-T6 Alloy was used. Aluminum 6061-T6 Alloy has high hardness and corrosion resistance. It is used in many areas, such as the defense industry, aircraft industry, railway industry, shipbuilding industry, bridges, pipes, transportation, and space applications. The chemical composition and mechanical properties of Al 6061-T6 Alloy are given in Table 1 and Table 2. The thicknesses of aluminum sheet metal are 1 mm and 1.5 mm. The dimensions of the v-bending test specimens are 70x70 mm.

Table 1. Chemical composition of 6061aluminium alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 6061	0.4-0.8	0.7	0.15-0.4	0.15	0.8-1.2	0.04-0.35	0.25	0.15	Balance

Table2. Mechanical properties of Al 6061-T6

Material	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation at break %	Brinell Hardness (500 g load, 10 mm ball)	Shear Strength (MPa)
Al 6061-T6	310	276	12	95	207

2.2.Method

The effects of sheet thickness, die angle, and die width on the springback behavior of aluminum 6061 alloys were examined by v-bending experiments. V-bending experiments were carried out on 1 m and 1.5 mm thick aluminum plates using 140°, 150°, and 160° dies. Experiments were carried out with three different die widths of 10, 16, and 20 mm. The experiments were carried out on a DENER brand press machine with a capacity of 135 tons. The press force applied for a 1 mm thick aluminum sheet is 3.1 tons, and for 1.5 mm, it is 4.6 tons. A view of the press machine is given in Figure 1. Experiments were carried out at constant speed. The parameters and their levels determined in the V-bending experiments are given in Table 3.

Figure 1. Press machine

Table 3. Experiments parameters and levels

Parameters	Level 1	Level 2	Level 3
Thickness (mm)	1	1.5	-
Die angle (°)	140	150	160
Die width (mm)	10	16	20

Schematic view of die and specimen in v-bending process is given in Figure 2.

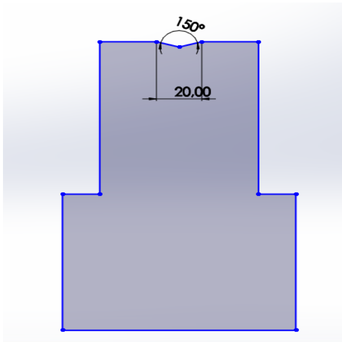

Figure 2. Schematic view of die in v-bending process (for die angle 150° and die width 20 mm)

The bending angle was measured in the specimens with a digital protractor. A view of the measurement of the spring back is given in Figure 3.

Figure 3. The view of digital protractor

3. Experimental Results

V-bending test results are given in this section. Experimantal springback results are given in Table 4.

When Table 4 is examined, springback is noted in the experiments performed with a 10 mm wide die on samples with 1 mm sheet thickness, and springing-go is noted in the bending processes performed in 16 and 20 mm wide dies. As the die angle increased, the springback angle increased for 10, 16, and 20 mm die widths. Similar results on aluminum A1100-O material were seen in the study conducted by Thipprakmas et al. Springback was observed at low bending angles such as 30° and 45°, and spring-go was observed at high bending angles such as 120° and 135°.

Similarly, in the same study, it was observed that springback decreased as the thickness increased [24]. Similar results were obtained in this study when the sheet thickness was 1.5 mm and the springback or spring-go behavior did not change. As the thickness increased, the spring back and spring-go values decreased. The variation of spring back depending on die angle and die width for two different sheet thicknesses is given in Figure 4.

When Figure 4 was examined, for 1 mm thickness and 10 mm die width, when the die angle was 140°, the springback was 0.2°, while at 160°, it increased by 4 times to 0.8°. With a die width of 16 mm, while the spring-go was -2° at 140°, it increased by 60% to -0.8° at 160°. With a die width of 20 mm, the spring-go increased by 44% to -1.5° at 160°, while it was -2.7° at 140°. When experiments were performed with different thicknesses using the same die angle, it was observed that the springback angle decreased as the thickness increased [25]. For 1.5 mm thickness and 10 mm die width, when the die angle was 140°, the spring-go was 0.1°, while at 160°, it increased by 7 times to 0.7°. With a die width of 16 mm, while the spring-go was -1.1° at 140°, it increased by 54% to -0.5° at 160°. With a die width of 20 mm, the spring-go increased by 44% to -0.9° at 160°, while it was -1.6° at 140°.

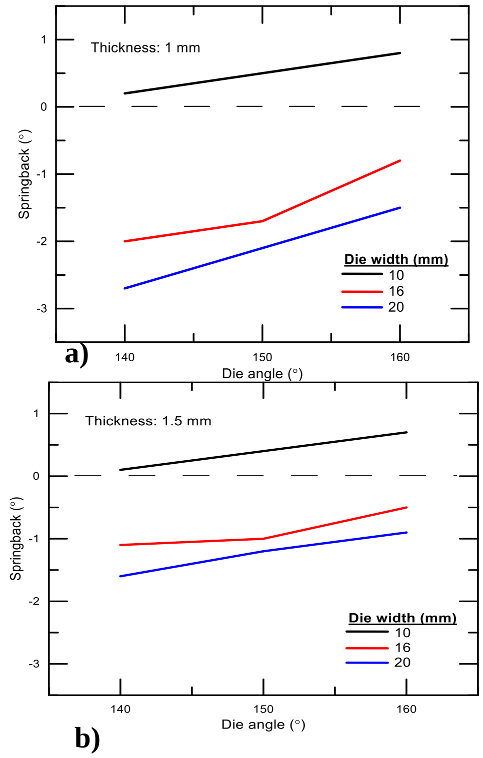

Figure 4. The variation of springback depending on die angle for a) 1 mm and b) 1.5 thickness

Table 4. Experimental results

Thickness (mm)	Die angle (°)	Springback angle (°) (Die width: 10 mm)	Spring-go angle (°) (Die width: 16 mm)	Spring-go angle (°) (Die width: 20 mm)
1	140	0.2	-2	-2.7
1	150	0.5	-1.7	-2.1
1	160	0.8	-0.8	-1.5
1.5	140	0.1	-1.1	-1.6
1.5	150	0.4	-1	-1.2
1.5	160	0.7	-0.5	-0.9

In Figure 4, it is clearly seen that the springback or spring-go decreases as the die width increases. As a result, when the plate thickness increases at any bending angle, springback values decrease. However, springback values were increased for sheets with the same thickness as the bending angle increased [26]. Similar results were found in the study conducted by Heng et al. on the 6061-T4 Al alloy. As the bending angle increased, springback values increased [27]. Springback or springback values decrease with increasing die width. In another study, springback behavior was examined by performing v-bending experiments on 6061 Al alloy. The effects of length, thickness and bending angle on springback were investigated. They reported that springback is more important in terms of thickness and bending angle, while length provides less effect [28]. View of the bent specimens is given in Figure 5-6.

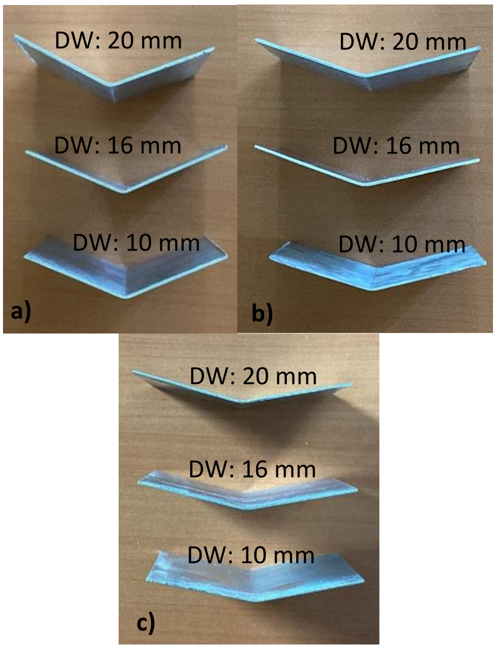

Figure 5. View of the bent specimens for 1 mm thickness, a) 140°, b) 150°, c) 160°

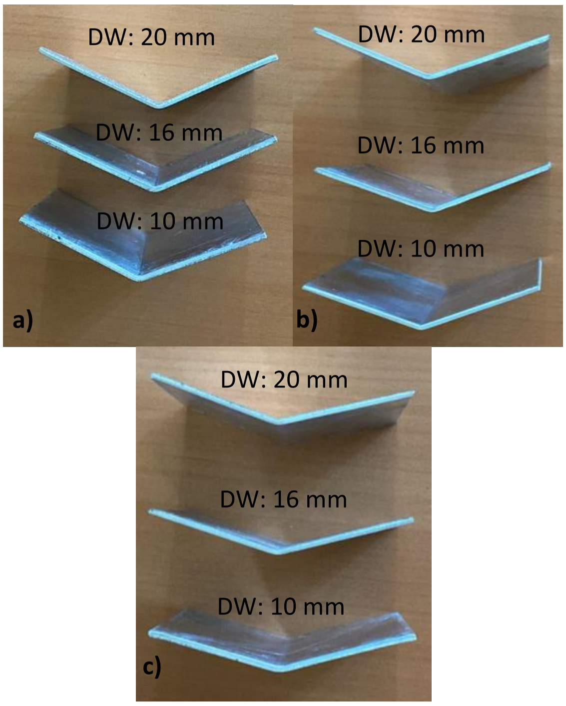

Figure 6. View of the bent specimens for 1.5 mm thickness, a) 140°, b) 150°, c) 160°

4. Variance (ANOVA) and Regression Analysis

Variance (ANOVA) and regression analyses were carried out using the Minitab 18 program.

4.1. Variance (ANOVA) analysis

Analysis of variance is used to determine the effect of different values of the independent variable or variables on the dependent variable. In Table 5, ANOVA results based on measured springback values are given. The parameters' contribution percentages are given in the table's last column.
Accordingly, the die width is the determining factor for springback.

In ANOVA, the importance of parameters is determined by comparing the F ratio of each parameter. The correlation coefficient (R^2) value of the analysis is 94.40%. The effect of sheet thickness on the springback value was determined as 5.20%, and the effect of the die angle on the springback value was determined as 10.73%. The most influential parameter on springback is the die width (78.42%).

Table 5. ANOVA results

Source	Df	Adj SS	Adj MS	F-value	P-value	Contribution %
Thickness (t)	1	0.9800	0.98000	11.16	0.006	5.20
Die angle (DA)	2	2.0233	1.01167	11.53	0.002	10.73
Die width (DW)	2	14.7633	7.38167	84.09	0.000	78.42
Error	12	1.0533	0.08778			5.65
Total	17	18.8200				100.00

4.2. Regression analysis

Regression analysis is a method used to determine the relationship between two or more variables. In this study, the dependent variable is springback, and the independent variables are die width (DW), die angle (DA) and sheet thickness (t). The prediction equation for springback given in Equation (1) was obtained by regression analysis. The correlation coefficient (R^2) of the equation obtained with the linear regression model for the springback value was 91.51%.
Regression equation:

Springback = -4.77 + 0.933 t + 0.04083 DA – 0.2164 DW (1)

5. Conclusions

In this study, the springback and spring-go behavior of 6061 Aluminum alloy was investigated experimentally by the v-bending process. Plates with 1 mm and 1.5 mm thickness were examined at 140, 150, and 160 die angles and 10, 16, and 20 mm die width. It was seen that the die width and the die angle significantly affected the springback behavior. Springback was observed at 10 mm die width and spring-go was observed at 16 and 20 mm die widths. As the die width increases, spring back or spring-go decreases. It was seen that the springback or spring-go increased as the die angle increased. It has been observed that sheet thickness has little effect on springback. As the sheet thickness increased, the amount of springback decreased. As a result of variance (ANOVA) analysis, it was seen that die width (78.42%) has a more significant effect on springback than die angle (10.73%) and sheet thickness (5.20%). As a result of the regression analysis, an equation giving the springback angle depending on the sheet thickness, die width and die angle was suggested.

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Authors' Contribution

The authors contributed equally to the study.

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No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Scienc

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